

DOT/FAA/PM-84/10

Program Engineering &
Maintenance Service
Washington, D.C. 20591

The Performance of Civil Airport Pavements with Lime-Cement-Flyash Base Course

132

AD-A144 614

Aston L. McLaughlin, Ph.D.

April 1984

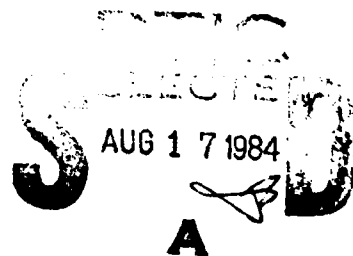
Final Report

This document is available to the U.S. public
through the National Technical Information
Service, Springfield, Virginia 22161.

DTIC FILE COPY



US Department of Transportation
Federal Aviation Administration



84 08 16 005

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

Technical Report Documentation Page

1. Report No. DOT/FAA/PM-84/10	2. Government Accession No. AD-A144 614	3. Recipient's Catalog No.	
4. Title and Subtitle THE PERFORMANCE OF CIVIL AIRPORT PAVEMENT WITH LIME-CEMENT-FLYASH BASE COURSE		5. Report Date April 1984	
		6. Performing Organization Code	
7. Author(s) Aston L. McLaughlin		8. Performing Organization Report No.	
9. Performing Organization Name and Address U. S. Department of Transportation Federal Aviation Administration Program Engineering & Maintenance Service 800 Independence Ave., S.W., Washington, D.C. 20591		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No.	
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Program Engineering & Maintenance Service 800 Independence Ave., S.W., Washington, D.C. 20591		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code FAA/APM-740	
15. Supplementary Notes Stabilizing			
16. Abstract The background and application of lime, cement and flyash are reviewed in order to explain the performance of civil aviation airport pavements constructed with lime-cement-flyash as a base course. The report states that performance of these pavements has been good and that the state of the art presently provides experimental techniques and laboratory tests to assure an economical and safe design. It is observed that many of the problems are associated with environmental forces and long-term behavior of the materials. A recommendation is that long-term performance together with the effectiveness of any remedial measures should be systematically monitored and catalogued so that any needed changes in the technology can be identified. Also, construction procedures and specifications limits can now be provided to the airport pavement engineering community on the basis of existing data and additional laboratory investigations.			
17. Key Words Airport Pavements Lime-cement-flyash Stabilization		18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, VA. 22151	
19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages 21	22. Price

PREFACE

This study was undertaken as an in-house effort by the Program Engineering and Maintenance Service of the Federal Aviation Administration (FAA) to review the in-service performance of certain civil airport pavements that were constructed with lime-cement-flyash bases. The effort was requested by the Office of Airport Standards, FAA, as part of a program to provide optimum standards for design and construction of pavements using alternative or locally available construction materials.

During the preparation of this report, Mr. Ray Fowler was Program Manager of the Airports Technology Program and Thomas O'Brien was Acting Division Manager. The Service Director was Mr. Martin Pozesky.

ACKNOWLEDGMENTS

The cooperation of engineers and managers at the Port Authority of New York and New Jersey, the Port of Portland, (Or), the City of Phoenix (Az), and the U. S. Army Corps of Engineers in Vicksburg (Ms) was vital to the execution of this project. Important information was also obtained from experts at the Soil Stabilization seminars offered by the University of Wisconsin Extension. The Office of Airport Standards, Federal Aviation Administration, also offered invaluable assistance.

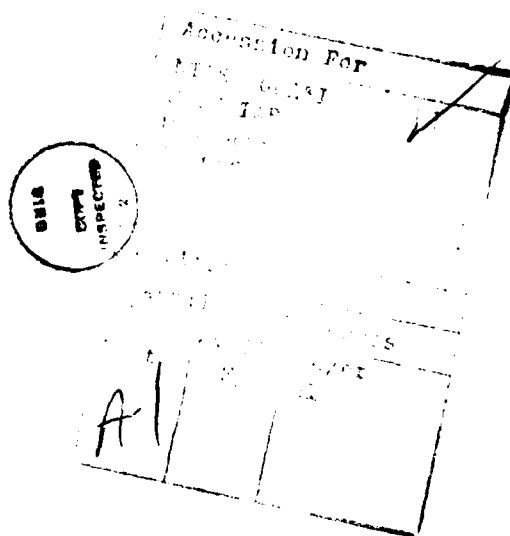


TABLE OF CONTENTS

	Page
I BACKGROUND	1
II APPLICATION	5
III PERFORMANCE	11
IV CONCLUSIONS	15
V RECOMMENDATIONS	16
VI SELECTED REFERENCES	17

I BACKGROUND

Mixtures of lime, clay and fibrous substances have been used as construction materials since ancient times. The technique is still used today in certain areas as a low cost or expedient structural alternative. Although the mineralogy of clays and the chemical reactions involved when clay is mixed with lime and water might not have been well understood, these materials were seen to perform satisfactorily in low stress applications and where environmental conditions were not too severe. Low initial costs and cheap maintenance labor have in many instances combined to make these mixes attractive to agencies with low revenue sources.

Studies on lime stabilization of soils at the Massachusetts Institute of Technology³ in the late 1950's have concluded that lime increases the soaked strength of certain soils but its effectiveness varies greatly with the soil type. Silts and organic soils are less responsive than plastic soils which may sometimes require years for full strength gain. It is also reported that soils often have an optimum lime demand above which there is no increase in soaked strength. In other parts of the literature⁹ it has been shown that optimum lime content for significant decreases in plasticity and expansiveness along with increased bearing strength varies from 4 to 8 percent by weight for most clays. Above the optimum percentage, excess lime may react with clay minerals in an ionic exchange to form calcium-silicate (aluminate) hydrates.

Other researchers believe that these insoluble hydrates do not form until the pH of the soil exceeds 7. The results of other work¹⁰ on the stabilization of pure clay minerals by hydrated lime have confirmed that the quantity of lime needed depends on the type of clay mineral to be treated. For instance, while unconfined strength gain began with the first increment of lime for kaolin clays, no

strength gain began in montmorillonite and illite clays until lime in excess of 4 to 6 percent was reached. This study was performed using X-ray diffraction analysis and differential thermal analysis.

The addition of cement to accelerate hardening and flyash as a filler for sand drawn from river sources is now being used to increase the bearing capacity of soils that would otherwise be objectionable to support highway and aircraft traffic. As sources of crushed stone deplete and haul distances increase, insitu materials will need to be stabilized to serve as base courses for heavy aircraft loads. A thorough knowledge of the changes of material properties due to continued chemical activity together with long term performance predictability has become important. Research sponsored by various local, state and Federal agencies has provided some basis for material and construction specifications. However, the capability of predicting pavement life based on the composition of lime-cement-flyash bases under a variety of environmental and traffic conditions does not exist.

Early pozzolans used in structural applications were in the form of volcanic ash. Modern practice utilizes flyash in place of volcanic ash and this substitution is not only due to availability but to superiority of particle gradation and a more desirable chemical content. Flyash contains silicon, iron and aluminum oxides which combine chemically in the presence of water and lime to form an insoluble cementing compound. Unlike lime, flyash is not a cementitious material but as a result of the chemical exchange with the lime a pozzolanic reaction develops and results in a considerable compressive strength gain in the mixture over a period of years⁴. The grain size of flyash also improves the gradation of the hydraulic sand which is often used in pavement construction and this adjustment renders increased stability to the mix.

Some experimentation on the use of lime-flyash to stabilize fine grained soils for highway bases was performed in the 1950's by the

University of Illinois² under the sponsorship of the Illinois Division of Highways. It was shown that the flexural modulus of elasticity of pozzolanic materials was virtually linear up to about half of the rupture strength and decreased at an increasing rate beyond that point. The modulus of elasticity also proved to be independent of the rate of loading unlike visco-elastic materials. The research team fabricated numerous laboratory specimens with different combinations of ingredients and followed up work with test track validation. Volume changes were observed to be high and these were according to the report due to moisture, temperature and frost. The effect of moisture was more pronounced on volume changes than any other cause and was even greater for fine grained soils. The study provided quality control techniques and a design methodology for the use of lime-flyash in highway pavements.

A study of the performance of lime stabilized native soil was conducted on behalf of the Federal Aviation Administration and reported in 1981⁷. Lime was used to stabilize native material to serve as base course for light aircraft pavements at Chino, CA, Big Bear, CA, and Payson, Az. between 1969 and 1975. Cement and flyash were not included in the soil which consisted of silty clay with some sand. The design consisted of 2 to 3 inches (5.1 to 7.6 cm) of asphaltic wearing course, 11 to 16 inches (27.9 to 40.6 cm) of lime-stabilized base course over 9 to 24 inches (22.9 to 60.9 cm) of compacted subgrade. The pavements were constructed in areas where temperatures ranged from -15 to 109 degrees F (-26 to 43 degrees C) and mean annual precipitation of 21 inches (53.3 cm). It was reported that although precise aircraft data were not available, service was acceptable. Wide variations in layer thicknesses were observed and although the design required quick-lime content of 4 percent, tests on field samples showed zero to 3.1 percent. There was no apparent relationship between the incidence of observed cracks, waviness or upheavals on the pavements with locations of insufficient layer thickness or low lime content. A noteworthy

observation from photographs taken at Big Bear was that one pavement heaved at a longitudinal crack as if compressive forces due to expansion of the base course were at work.

The U.S. Corps of Engineers⁵, in work co-sponsored by the Federal Aviation Administration, conducted full scale tests on pavement sections with various subbase stabilizing materials. The relative performance of these sections under accelerated trafficking was to be determined. Through the use of equivalency factors with control sections designed with conventional crushed stone subbase, it was found that lime-cement-flyash (LCF) subbases were equivalent to 123 percent to 146 percent of the conventionally design thickness. This research did not include direct testing of LCF as a base course material. However since stabilized base course material is accepted at one-half the equivalency of stabilized subbase material, LCF was not recommended as a base course. The report suggests that the LCF subbase should have had equivalencies of more than 200 percent in order for the same composition to be used as a base course. The optimal proportions of lime, cement and flyash were determined on the basis of maximum unconfined compressive strength, water content, and other factors outlined in Military Pavement Design Standards⁶.

Because the pozzolanic reactivity and chemical composition of flyash vary from one source to another, the suitability of any particular supply should be determined by standard procedures such as described in ASTM C593. Some LCF mixes have been prepared with from 2 to 8 percent of lime and from 8 to 36 percent by weight of flyash.

This report addresses the application and performance of lime-cement-flyash bases on airport pavements. The narrative is based on literature surveys, interviews with cognizant engineers, and airport pavement inspections.

II APPLICATION:

The most extensive use of lime-cement-flyash as a pavement material has been by the Port Authority of New York and New Jersey in the construction of runways or taxiways at Newark International and Kennedy International airports during the 1960's. During this period electric generating plants were primarily coal burning and large amounts of the residue, flyash, were piled near the furnaces. It is reported that on the Newark airport project nearly 2 million tons (1.8 million tonne) of lime-cement-flyash were used and this included about 300,000 tons (270,000 tonne) of flyash.

Construction site for the Newark airport runway pavements was in a flood plain with an average elevation inches above sea level. Native soil was meadow mat and marshland composed of decaying organic matter. This material was at least 15 feet (4.6 m) thick, and excavation and replacement with a higher grade of soil would have been prohibitive. The areas for development were reclaimed with hydraulic sand fill dredged from the sea. It was reported that during the pumping operations fines in the sand were separated out leaving a uniform size (30 to 50 mesh size) for deposit at the site. Thus, some aggregate interlocking capability was lost. It has been shown in the literature⁴ that if soil gradation is in a narrow band of particle size distribution as demonstrated by beach sand and hydraulic fill the material is not stable enough to sustain heavy loads. This deficiency of finer sand particles was corrected by the introduction of some lime and flyash material. It was reported during visits to Newark International and Kennedy International Airports that about 2.5 million square yards (2.1 million m²) of pavement was constructed with base courses of LCF materials prepared in central mixing plants.

Before pavement construction began at Newark International Airport, a total of 5 feet (1.6 m) of sand was deposited for use as base and

another layer was deposited for use as surcharge to achieve consolidation and to minimize in-service settlement.

Because materials such as lime, cement and flyash were more readily available and economically more feasible than conventional materials, a proposal was made to utilize them in the construction. Laboratory and traffic tests were subsequently conducted to provide data so that design criteria and construction procedures could be evaluated and if the results proved satisfactory then specifications could be developed. Consolidated Edison of New York was one of the suppliers of flyash, and laboratory and field tests were performed by personnel from the Authority. (Some research had been done by agencies in France but because of differences in material properties and gradation, results from that research were not utilized.) It has been reported that about \$500,000 was spent in research on the behavior of LCF mixes before specifications for these projects were written.

The lime used in the LCF construction of airport pavements generally consists of various blends of quicklime, hydrated lime, and hydraulic lime. Suggested specifications for lime to be used in combination with pozzolans may be found in ASTM C207 Type N, but laboratory testing should always be conducted to determine optimum performance and thickness design versus the types of material that are available. The construction of Newark Airport pavements included specifications that the lime ingredient should have a total nonvolatile oxide content (CaO & MgO) of not less than 86 percent by weight. Substitution of high oxide lime (dolomitic hydrate) was allowed provided that the total oxide in the mix was not less than the specified amount in hydrated lime. It was also specified that a minimum of 75 percent by weight should pass through the no. 200 sieve size¹.

Suggested sources of flyash were the Public Service Electric & Gas Company of New Jersey, Metropolitan Edison Company in Pennsylvania,

and New York State Electric & Gas Company in New York. ASTM C-593 provided the applicable testing procedure except as modified such that loss by ignition was not to be more than 10 percent, combined content of silica oxide (SiO_2) and Aluminum Oxide (Al_2O_3) should not be less than 50 percent. The minimum 7-day compressive strength measured at 130 degrees F (54 degrees C) of the lime-pozzolan specimens was not to be less than 600 pounds per square inch (4.1 MPa).

The coarse aggregate was crushed trap rock consisting of hard durable particles. 100 percent by weight should pass through the 1.5-inch (3.8-cm) sieve, 60 to 90 percent through the 1-inch (2.5-cm) sieve, and 0 to 15 percent through the 0.5-inch (1.3-cm) sieve. Sand was obtained from prescribed locations for use on the project. Specification required that not more than 10 percent of the sand should pass through the no. 200 sieve. The portland cement used in the construction was Type 1 cement conforming to ASTM C-150.

The New York airport pavements were designed for the operation of the B-747 aircraft and for future aircraft with gross weight of 500 tons (450 tonne). According to a report by one noted authority⁴, a 28-inch (71-cm) thick LCF base was installed as a substitute for 18 inches (45.7 cm) of portland cement concrete or 43 inches (1.1 m) of aggregate based asphalt concrete. This pavement was installed for \$7.60 per square yard (\$6.23 per sq. m) compared with \$12 for a conventional flexible pavement and \$20 for a conventional rigid pavement. In addition to the obvious price advantage, it was reported that the new type of pavement was expected to gain in strength over a period of at least 5 years, thereby compensating for projected increases in aircraft sizes and weights.

The following table shows the composition of three mix types used for various levels in the pavement cross section:

Composition of Lime-Cement-Flyash Mixes (Percent Dry Weight)

Type Mix	Hydrated Lime	Portland Cement	Flyash	Aggregate	In-Place Fill Sand
A	3.6	0.9	11	30	54.5
B	3.2	0.8	13	0	83.0
C	2.8	0.7	13	0	83.5

The water content requirement was 8 to 10 percent by weight of the mix.

Late in 1973, a 2,200 (671 m) foot runway extension was to be designed for Portland International Airport in Oregon¹¹. The engineers and planners agreed that a lime-pozzolan stabilized base would be more economical than a full-depth asphaltic pavement and would also reduce construction time. An important ingredient of the mixture was to be Columbia River sand which was essentially unisize with most of the particles falling between the no. 10 and no. 100 sieve sizes.

Three different blend types were designed for application in either the keel section, pavement edges, or shoulder area. Runway edge requirements were for 14 inches (35.6 cm) of lime-cement-pozzolan-filler (LCPF) Type B to be placed over the subgrade, followed by 9 inches (22.9 cm) of LCPF Type A, topped with 3 inches (7.6 cm) of asphalt concrete (AC). Runway keel sections required 8 inches (20.3 cm) of LCPF Type C over the subgrade, followed by 14 inches (35.6 cm) of LCPF Type B, then 8 inches (20.3 cm) of LCPF Type A, topped with 4 inches (10.1 cm) of AC. The shoulder areas required 8.5 inches (21.6 cm) of LCPF Type A with a 1.5-inch (3.8-cm) AC topping. The proportions of ingredients and the expected mechanical properties are shown in the following Tables.

LCPF COMPOSITION
PERCENT BY DRY WEIGHT

<u>Material</u>	<u>Type A</u>	<u>Type B</u>	<u>Type C</u>
Lime	3.3	3.0	3.0
Cement	1.1	1.0	1.0
Pozzolan	6.6	6.0	6.0
Stone	25.0	10.0	-
Silt Filler	8.0	10.0	10.0
On-Site Sand	56.0	70.0	80.0

LCPF PROPERTIES
(APPROXIMATE)

<u>Property</u>	<u>Type A</u>	<u>Type B</u>	<u>Type C</u>
Modulus	1×10^6 psi (6.9×10^6 kpa)	5×10^5 psi (3.5×10^6 kpa)	2.5×10^5 psi (1.7×10^6 kpa)
Compressive Strength Ultimate	2000 psi + (13.8×10^3 kpa)	1500 psi + (10.5×10^3 kpa)	800 psi + (5.5×10^3 kpa)

(Based on the experience of the Port Authority of NY and NJ with fine sands and studies in the University of Illinois Materials Research Laboratory, it was believed that LCPF would likely provide the most cost effective base at this airport¹². But, the final criteria for the various blends, cost analyses, dimensional stability, design and construction considerations were determined only after a great deal of laboratory investigation and research by consultants knowledgeable in this kind of pavement.)

A continuous flow mixing plant supplied the blended ingredients which were loaded into trucks for deposit on grade in lifts of about 4 inches (10.1 cm). These lifts were then rolled with a vibratory steel-wheel roller and final compaction was achieved by the use of a pneumatic roller. Joints were later saw cut at 200-foot (61-m) intervals for the structural pavement and at 50-foot (15-m) intervals for the shoulder to facilitate thermal movements. Prior to installation of the wearing course, the compacted LCPF base was treated with a prime coat of MC-70 cutback asphalt at the rate of 0.2 to 0.25 gallon per square yard (0.9 to 1.1 liter per square meter) and allowed to cure.

III PERFORMANCE

Inspection of the New York and New Jersey airports in the spring of 1982 revealed no greater signs of pavement distress than on conventionally designed pavements. One reason for this might have been the immediate attention given to maintenance problems at the airports. However, there were certain problems that arose with the pavement that had to be remedied from time to time.

The following passage outlines the substance of discussions and correspondence¹³ with engineers at the Newark International Airport and relates to some of the pavements there:

"Extensive cracking of the asphalt concrete wearing course, a condition which allowed rain water to gain access to the surface of the LCF concrete and cause deterioration of the interface, became apparent. This condition was thought to be a result of three items:

- * The use of a hard (low penetration) asphalt binder, a more brittle material than the normally used binders, which was selected to resist the plastic deformation that can occur under very heavy loads.
- * The lack of adequately spaced joints within the original pavement to handle the differential expansion that occurred between the LCF material and the asphalt concrete wearing course. This latter condition became more apparent as the LCF material's compressive strength increased as it aged and as it began to behave much like a lean concrete material.
- * The inability of the initial joint sealant material used to provide a long lasting, durable seal within the cracks, joints and in-pavement lighting systems wire kerfs.

Some remedial work involved removal of the asphalt concrete wearing course, installing the wires for the in-pavement lighting system in conduit grouted within slots lying beneath the surface of the LCF material, placing a one-inch (2.5-cm) thick hot mix membrane over the exposed LCF surface, and restoring the asphalt concrete wearing course using an AC-20 binder material.

Other remedial work included saw-cutting the AC wearing course to match any joints below, installing new control joints at intermediate locations between the original expansion joints, and sealing the joints and any remaining wire kerfs with a rubberized asphalt binder material conforming to federal specification SS-S-1401B. New pavements now use expansion joints placed 150 feet (46 m) on center with two intermediate control joints placed 50 feet (15 m) center-to-center. The expansion joints are installed completely through the asphalt concrete wearing course and into the top two layers of LCF material. The control joints are installed in the top layer of LCF material to a depth equal to 1/4 the thickness of that layer and in the asphalt concrete wearing course to a depth equal to 1/4 the depth of that layer.

At some taxiways, ramps and at the end of the runways, both representing areas where aircraft turn and create high shear forces, there was the incidence of slippage of the wearing course over the LCF base. An explanation was that adequate bond could not be developed between the flexible wearing course and the LCF surface. Some remedial work involved removing the asphalt concrete wearing course, roughing up the top of the LCF base course to provide improved mechanical interlock, and then replacing the asphalt concrete wearing course with one made of a binder material which included 25% natural lake asphalt. In areas of extremely high stress, i.e. where aircraft snapped on the runway, fibrous concrete was used as the wearing course".

On some taxiway ramps at Kennedy International Airport, there was the incidence of slippage of the wearing course within its own depth and over the LCF base. This was more common at turning areas where shear forces were high. One explanation here was that at construction adequate bond might not have been provided between the two layers. Another explanation was that the asphaltic concrete mix consisted of small-sized aggregate (3/8 inch, 0.9 cm, maximum size) and that this did not provide sufficient interlock to resist shearing forces. Some remedial work involved removing the wearing course, cleaning the top of the LCF base course, tack coating, and then replacing the wearing course. It should be noted that if rain water does react with the LCF base course surface and a powdery residue develops, bond will be lost and slippage under shearing forces will most likely result.

During a site visit to Phoenix International Sky Harbor airport in the spring of 1984, it was noted that a now 10-year-old runway and taxiway extension was constructed using cement treated subbase. A visual inspection of the area did not show any signs of distress that could be attributed to the method of stabilization. However, nondestructive testing through the use of the Dynaflect machine has recently shown that the taxiway pavement is stronger than the runway portion and consideration is being given to upgrade the weak areas. The authorities could not explain the cause of the difference in strength. As far as is known no pavement at this airport was constructed using lime-cement-flyash combinations in the supporting layers.

It was reported at a 1984 seminar on Stabilization Techniques at Reno, Nevada that one street in Las Vegas, Nevada, stabilized with lime has suffered severe surface distortions since construction. It has been suggested that sulfate salts in the soil might be the source of deleterious reactivity with the lime thereby creating swelling and buckling. The subgrade material was native clay which was a reason why lime was chosen as the stabilizing agent.

It was also emphasized that clay stabilization with lime cement or flyash involves very complex and long-term chemical reactions, and that extensive soil analyses and tests should be conducted before a mix is selected. Particle size, gradation, reactivity, plasticity index, pH concentration, degree of drainage, ratios of calcium to magnesium ions, ratios of silica to sesquioxides, presence of organic material, sulfates and carbonates, and general clay mineralogy should be studied prior to design. The Federal Highway Administration⁸ has published a comprehensive guide book on the use of stabilizing agents for highway pavements. Equipment manufacturers and contractors have also developed effective techniques for batch mixing and in-place mixing that have greatly reduced time of construction and labor costs.

As stated earlier, the Portland International Airport authorities in Oregon completed 2,200 feet (671 m) of runway extension and parallel taxiway over a fill of dredged river material. This was reported in an interview with a knowledgeable airport official and also stated in the literature¹¹. A visual inspection early in 1984 showed no signs of pavement distress and reports state that performance has been excellent. Some longitudinal cracks between the taxiway and shoulder areas were apparent but these were due to stresses developed there because of a change in section thickness. The pozzolan utilized in this construction was not flyash or volcanic dust but was a finely ground deposit of shale with high siliceous content.

IV CONCLUSIONS

It appears that many pavement and geotechnical engineers view lime-cement-flyash base courses as a viable material for use in the construction of pavements when conventional (in the sense of what FAA recommends) materials are either not economically feasible, unavailable, or of poor quality. The art of utilizing native materials and increasing their strength through stabilization has existed over a long period of time. While the amount of ingredients has been largely arrived at by experience, experimental techniques and tests have been developed to determine the quality and reactivity of the ingredients before the final mix is decided upon.

The mixture of soil material with materials such as lime, cement, or flyash initiates complex, long-lasting chemical reactions which under the right conditions of temperature and moisture can produce a substance with new mechanical properties. However, changes in the insitu conditions during the life of the pavement may produce new by-products that are detrimental to the performance of the pavement. Such situations may develop because of the ingress of water laden with sulfates and carbonates or generally a lowered pH of the ground water. There is evidence that engineers at airports where these designs have been installed are aware of these possibilities and have an established program of monitoring, coring and nondestructive testing to assure continued effective performance of the pavements.

The combination of increasing aircraft payloads, traffic frequency, scarcity of materials for conventional construction and scarcity of sites with good subgrade bearing values will make it more and more necessary for engineers to consider stabilization as a means of strengthening the pavement structure. It has been expressed in many interviews that the situation is acute in rural localities where the only access is by air.

V RECOMMENDATIONS

Based on the work conducted in the preparation of this report the following recommendations are made:

- 1 Chemical activities and material properties of various combinations of lime, cement, flyash should be studied to establish limits for airport pavement application. Construction, design and quality control procedures based on the results of existing data and new theoretical, laboratory and field tests should be provided to airport pavement engineers.
- 2 Long-term performance of this expedient type of pavement system should be monitored, and remedial measures when applied should be documented on a systematic basis.
- 3 A model should be developed to predict the fatigue life of the base course, and this model should be based on loading time and rheological properties of the lime-cement-flyash combinations.
- 4 The effects of deleterious substances that degrade this material and the change in properties or cross section that may occur should be investigated.

VI SELECTED REFERENCES

- 1 Construction Specifications, Newark International Airport, New Jersey, Section 2I, Contract NIA 520 143.
- 2 Ahlberg, H. L. and E. J. Barenberg, "Pozzolan Pavements," Bulletin 473, Engineering Experiment Station, University of Illinois, Urbana-Champaign, 1965.
- 3 Ladd, C. C. et al, "Recent Soil-Lime Research at the Massachusetts Institute of Technology", Highway Research Board, Bulletin 262, p. 64, Washington, DC, 1960.
4. Yang, Nai C., Design of Functional Pavements, McGraw Hill Book Company, New York 1972, page 130
- 5 U.S. Corps of Engineers, Comparative Performance of Structural Layers in Pavement Systems, Volume II, FAA-RD-73-198-II, Waterways Experiment Station, 1977
- 6 Department of the Army, Headquarters, "Soil Stabilization for Pavements," Technical Manual TM 5-822-4.
- 7 Brownie, R. B., Lime-stabilized Native Soil As a Base Course for Light Aircraft Pavement, 1981, DOT/FAA/RD-80/112
- 8 Soil Stabilization in Pavement Structures, A User's Manual, FHWA-IP-80-2, Department of Transportation, October 1979
- 9 Jones, Chester W., "Stabilization of Expansive Clay with Hydrated Lime and with Portland Cement", Highway Research Board, Bulletin 193, p. 40, Washington, DC, 1958
- 10 Eades, James L. and R. E. Grim, "Reaction of Hydrated Lime With Pure Clay Minerals in Soil Stabilization", Highway Research Board, Bulletin 262, p. 51, Washington, DC, 1960.
- 11 Byington, Marvin and Gene Arnold, "LCPF Pavement at Portland International Airport," Paper presented to the A O C I. Annual Standing Committee Meeting, 1974.
- 12 Barenberg, E. J. et al, Private Communication on "Report on findings and Conclusions from a Materials Evaluations Study Conducted for Port of Portland, Oregon," Champaign, Illinois, 1973 (Unpublished)
- 13 Jensen, George A., Private Communication, Plant and Structures Division, Newark International Airport, July 1984.